

Mu2e Pion Production Target

CD1 Internal Review
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Collaborators

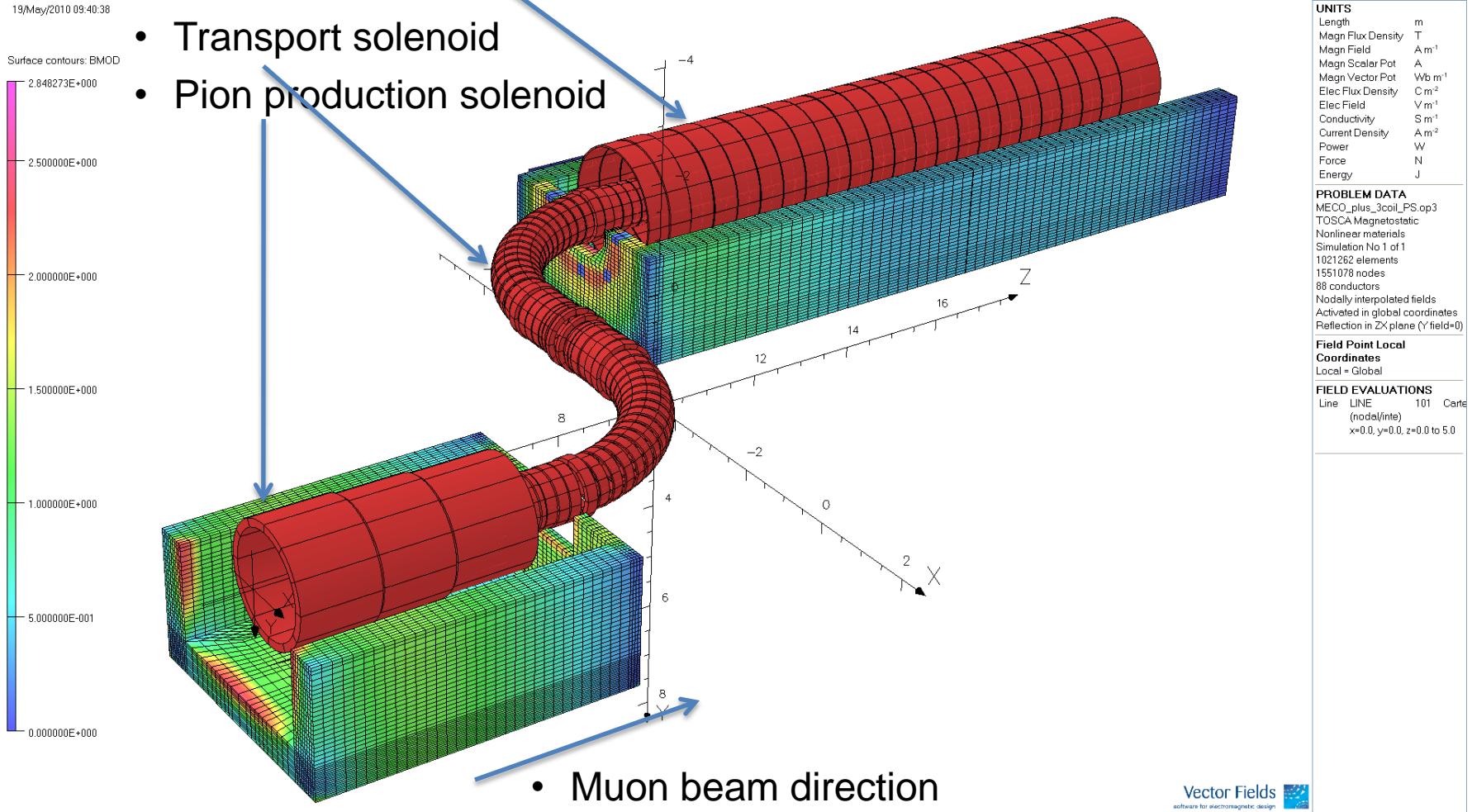
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- R.Coleman
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- J.Popp
- E.Rivera
- Magnet Group: FNAL Technical Division

Conceptual Design Projects

- Pion production target
 - Beam Power: 25 kW, 2×10^{13} protons/sec, Kinetic energy per proton: 8 GeV
 - High interaction rate: high Z and high-density material
 - Energy Deposition: 2150 W
 - Cooling
 - Radiation → mechanically unstable
 - Single-phase water jet → studies reveal this is a robust method
 - Primary figures of merit:
 - Maximize stopped muon yield in Detector Solenoid target: $\sim 10^{11}$ stops/sec
 - non-boiling condition on water: single-phase flow
 - mechanical stability
 - Pumping station (Contract with RAL Engineers)
- Target remote handling system (Contract with RAL Engineers)
 - Installation
 - Removal
 - Storage

Mu2e Solenoids & Iron

- Detector solenoid
- Transport solenoid
- Pion production solenoid

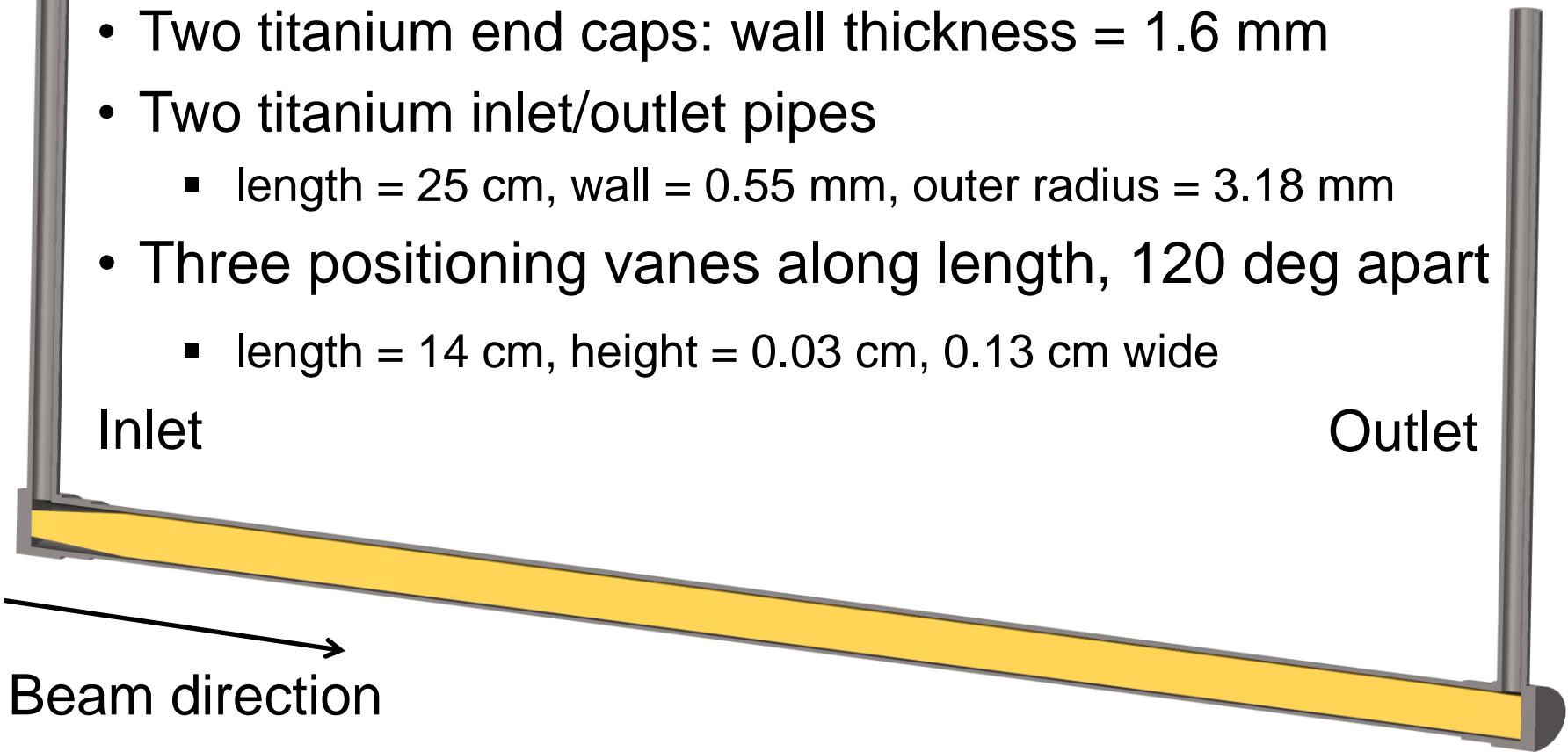


Downstream View of Muon Beam Line

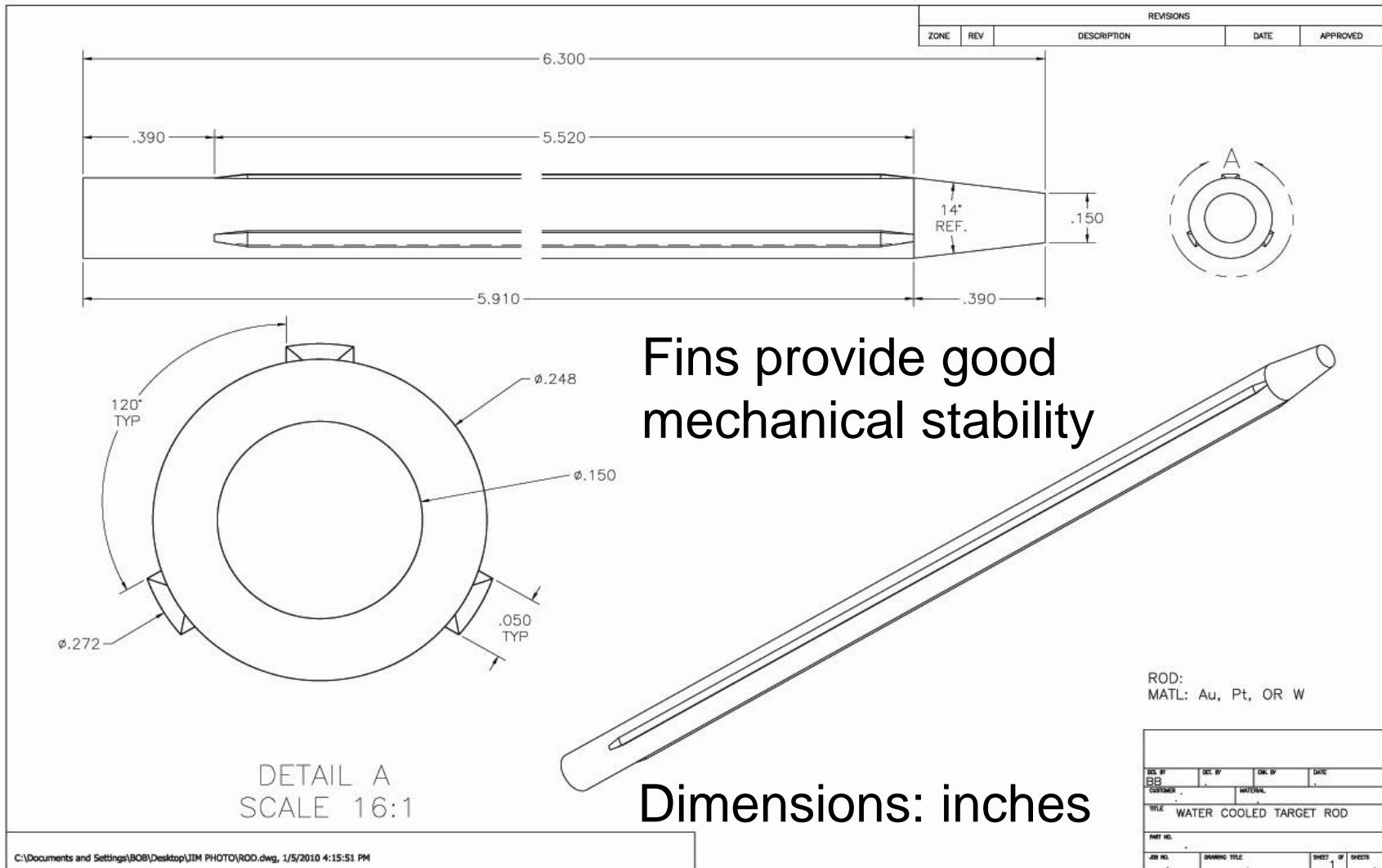
- Inside pion Production Solenoid
 - Target hangs from the heat shield
 - Gold cylinder
 - Annular water channel
 - Proton beam enters through port in the shield
 - Target lies in a graded magnetic field
-

Target Baseline Details

- Gold rod: length = 16 cm, radius = 0.3 cm
- Annular water channel: gap = 0.03 cm
- One titanium tube: wall thickness = 0.5 mm
- Two titanium end caps: wall thickness = 1.6 mm
- Two titanium inlet/outlet pipes
 - length = 25 cm, wall = 0.55 mm, outer radius = 3.18 mm
- Three positioning vanes along length, 120 deg apart
 - length = 14 cm, height = 0.03 cm, 0.13 cm wide

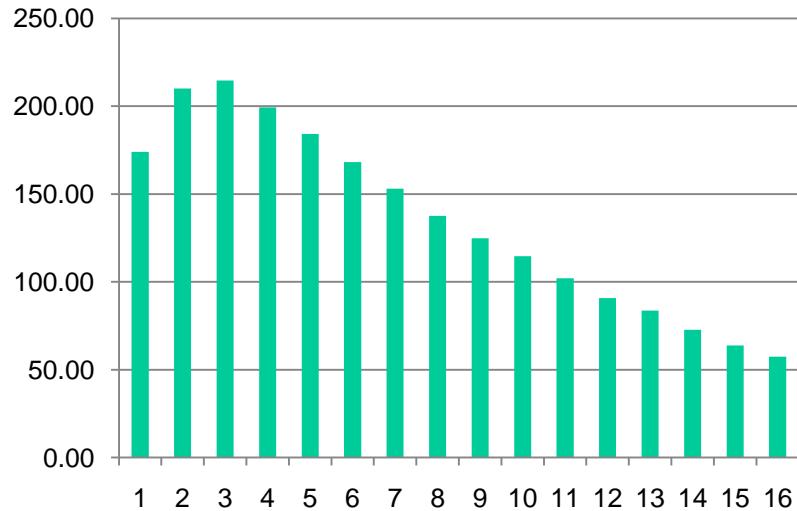


Water-Cooled Target Rod – 3 Fins



MARS: Power Distribution in Gold Cylinder

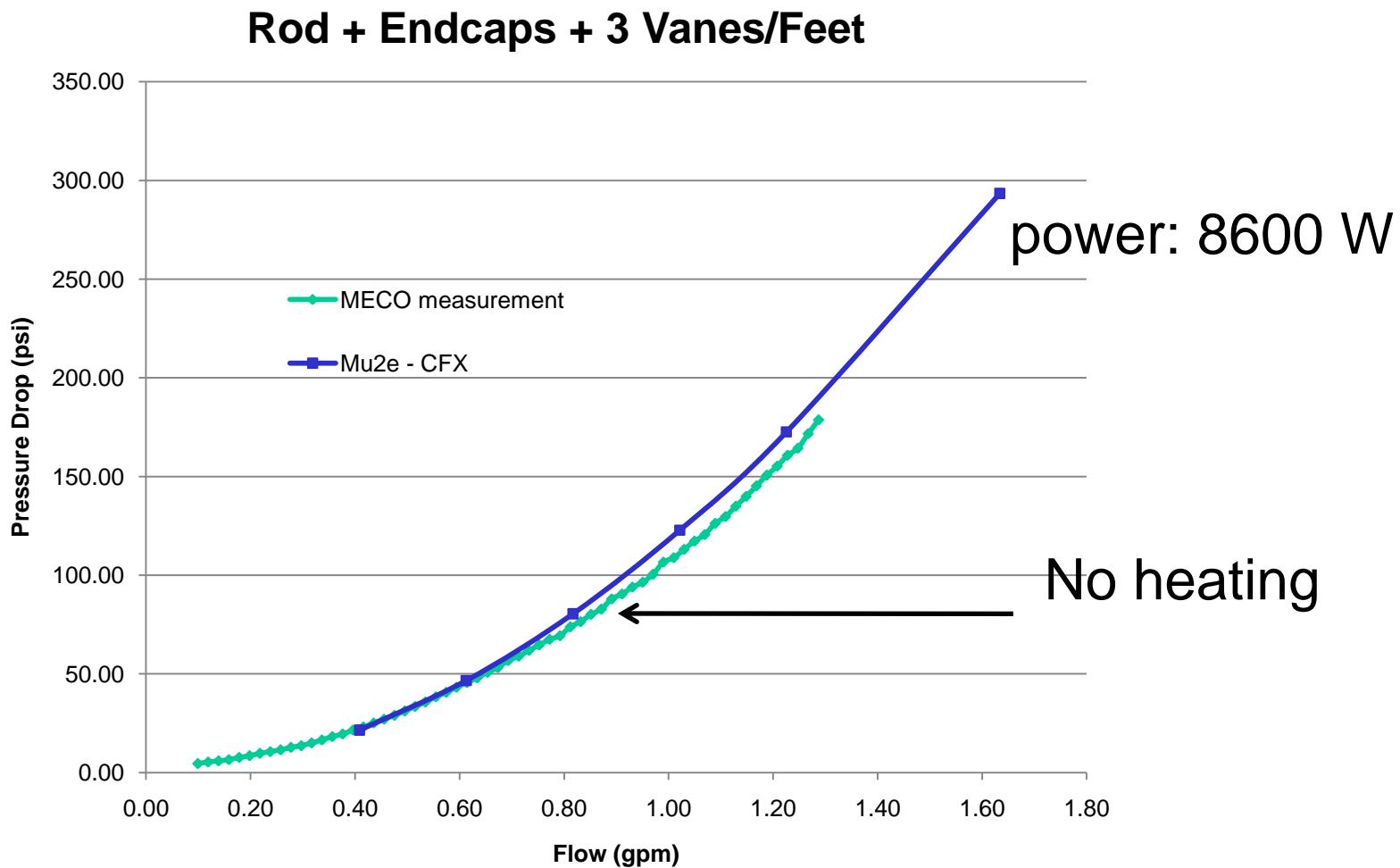
- Actual average total power in target rod: 2150 W



- Prefer safety factor: 4-5
- Mu2e design power: 8600 W
 - Axial bins: 1 cm
 - Radial bins: 0.06 cm
- Heating: steady state

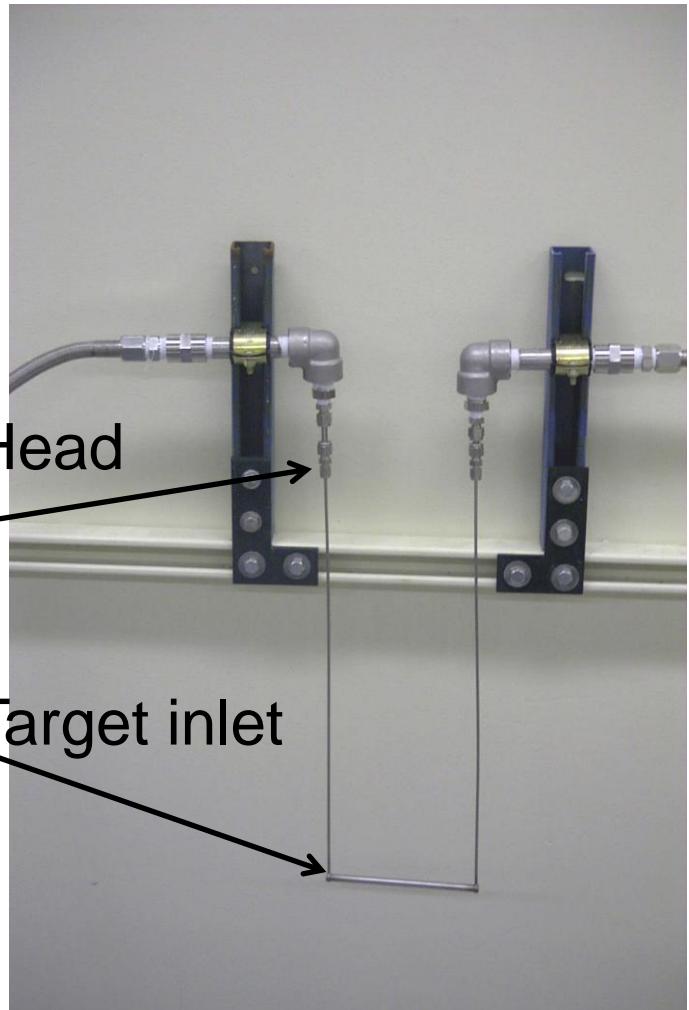
- Horizontal axis: one cm bins along length of target
- Proton beam parameters:
 - 8 GeV kinetic energy
 - Gaussian spatial distribution
 - Radial standard deviation = 1 mm

Rod + Shell + Fins + End Caps vs Experiment



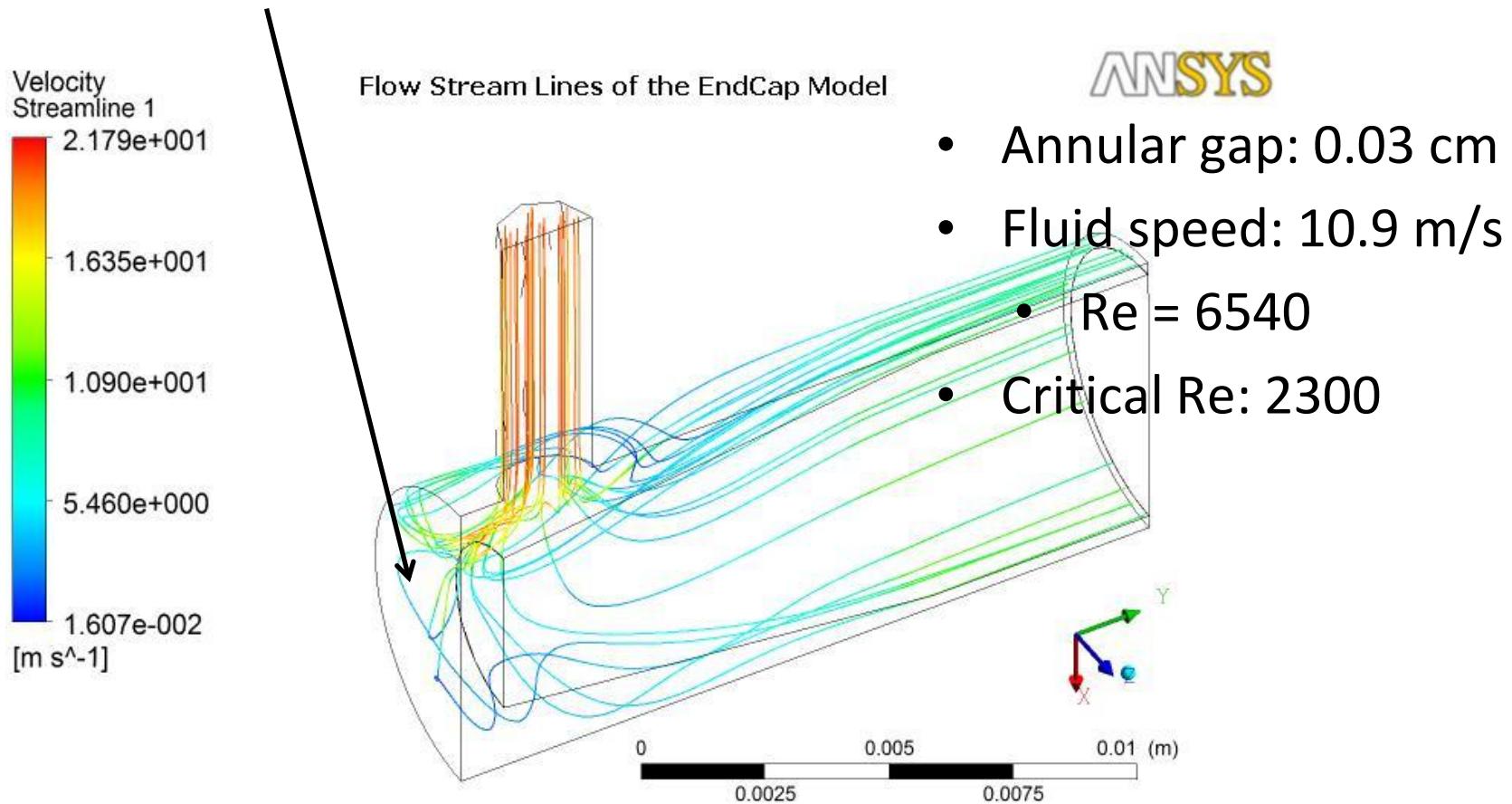
Controls & Operating Limits

- Primary controls besides beam parameters
 - Inlet & outlet geometry
 - Flow rate
 - Head pressure, Outlet pressure
- Limit: Titanium alloy yield point
 - 170 – 1100 MPa
- Flow rate = 1 gpm
 - Water pressure
 - head = 241 psi
 - target inlet = 190 psi
 - Inlet inner pipe hoop stress
 - head = 4.41 MPa
 - target inlet = 3.26 MPa
 - Cylindrical shell inner hoop stress
 - target inlet = 9.34 MPa



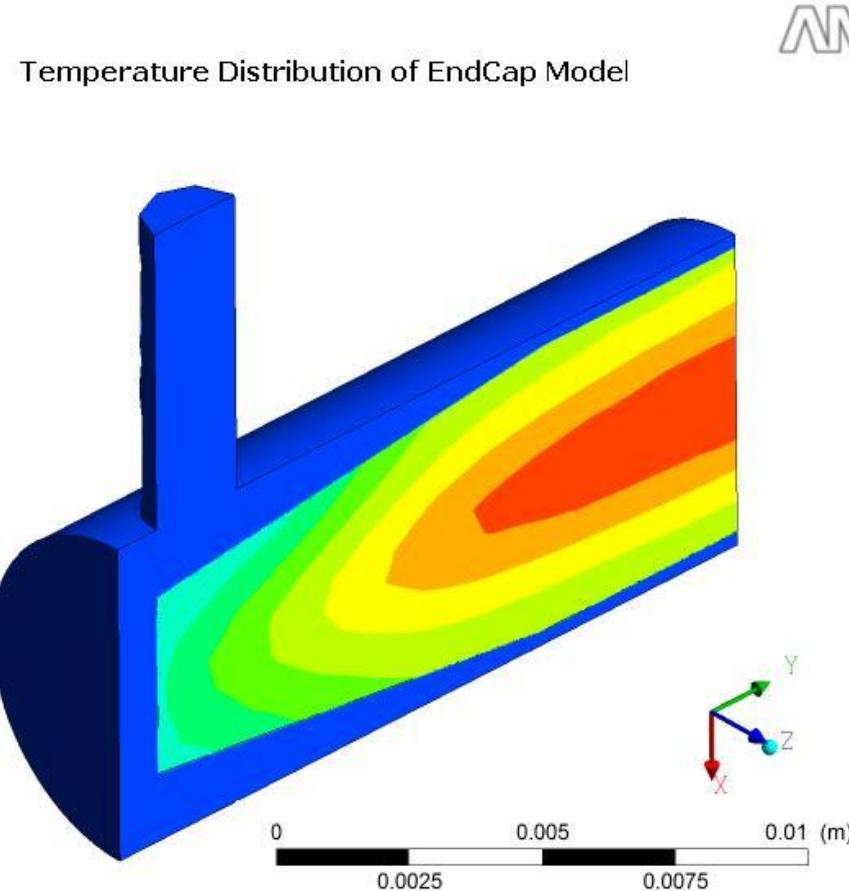
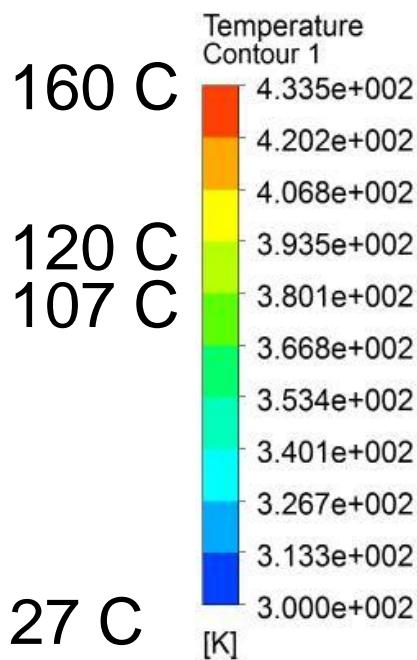
Heat Transfer at Target Inlet

- Axial thermal expansion: 0.03 cm
- Crucial entrance gap: 0.06 cm



Temperature Profile at Inlet

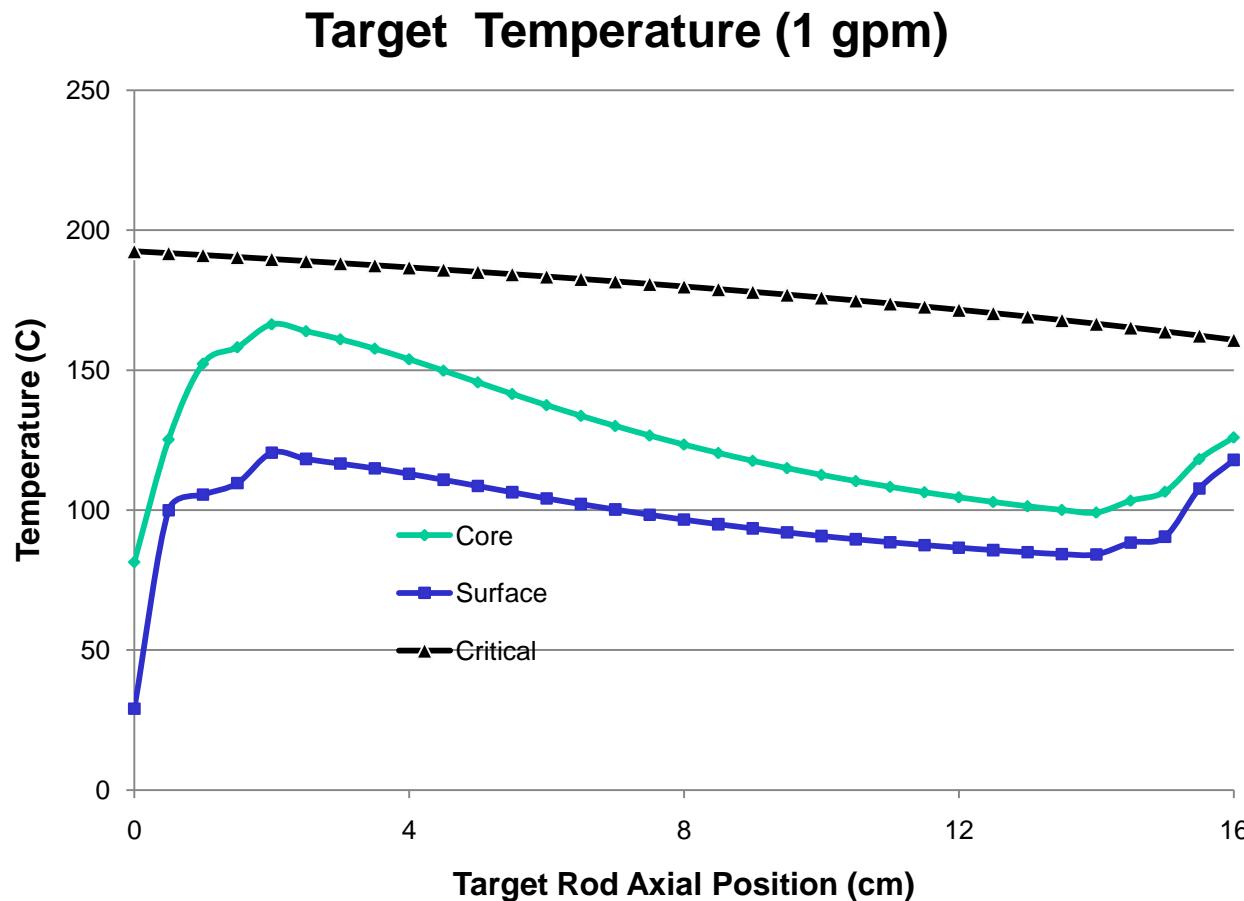
- Inlet water temperature: 25 C
- Flow rate: 1 gpm



- Melting point: Au
 - 1060 C

Overall Coolant Stability

- Max. coolant temperature at the target surface



Conclusions

- Calculations show that a radiation-cooled target is mechanically unstable.
- Calculations and measurements indicate that a water-cooled target provides adequate target and coolant temperature control.
- Issues yet to be fully examined
 - Radiation safety
 - Water hammer from accidental beam steering
 - Vibration isolation

Summary of Target Docs: Docdb

- 986-v1, MECO Reference Design Document: WBS 1.3.1 Production Target
- 985-v1, MECO Production Target Research Summary
- 887-v2, Production Target Requirements
- 796-v1, Water-Cooled Pion Production Target Progress
- 793-v1, Water-Cooled Pion Production Target for the Mu2e Experiment
- 739-v2, Production Target Progress
- 711-v2, Radiation-Cooled Tungsten Target for Mu2e Experiment
- 694-v1, MECO Production Target Issues
- 647-v1, Thermal Stresses in Pion Production Target
- 526-v2, MECO Production Target Design
- 195-v1, MECO101 -- Heat Transfer Analysis of a Water-Cooled Production Target for MECO
- 188-v1, MECO094 -- Effect of Water Channel and Containment Shell Thickness on Muon Stopping Rates for the Water-Cooled Production Target

Summary of Target Docs: Docdb

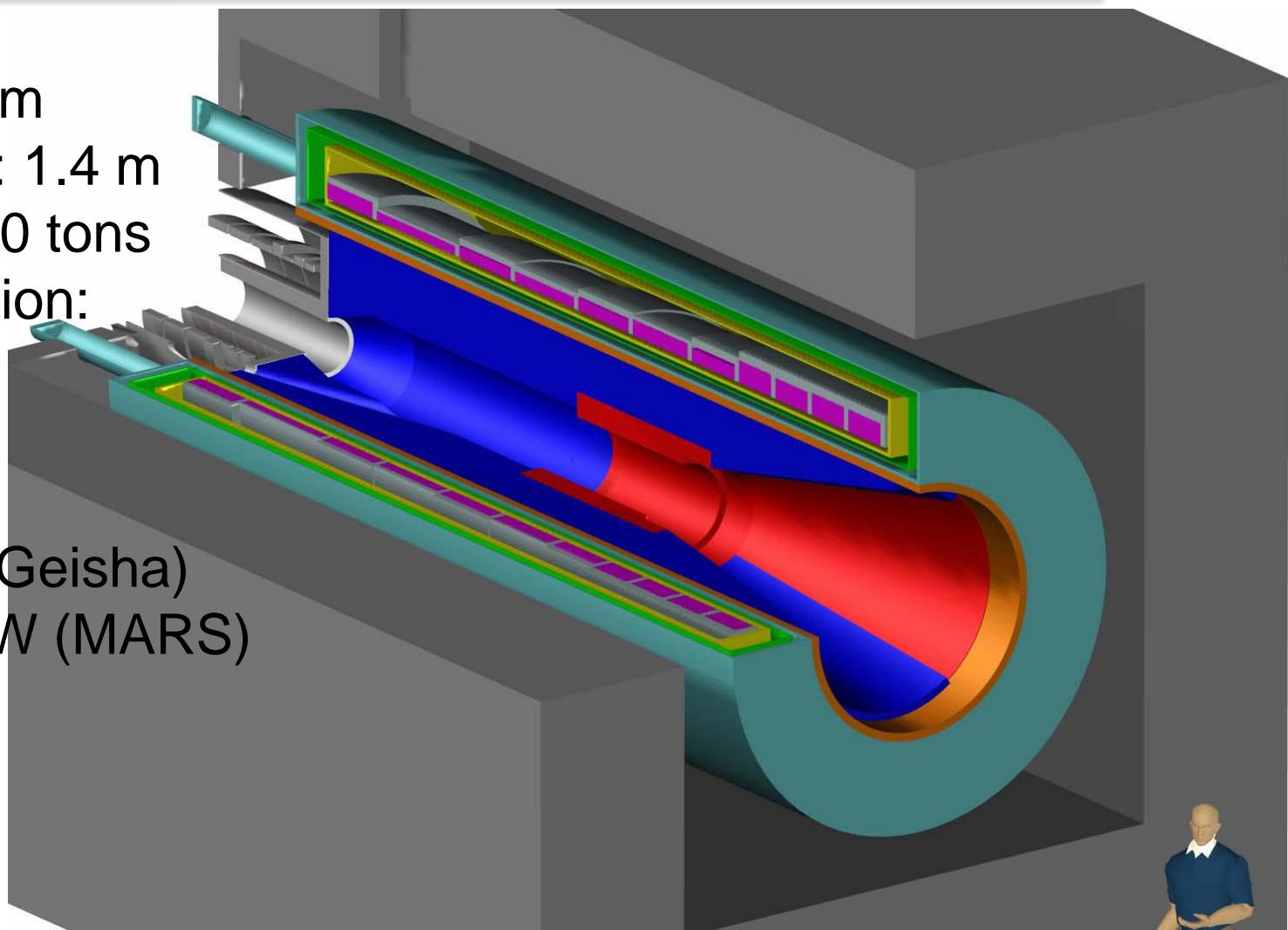
- 186-v1, MECO092 -- Review of Thermal Stresses in a Radiation-Cooled Target for MECO
- 184-v1, MECO090 -- Research Proposal for a Water-Cooled Pion Production Target
- 180-v1, MECO086 -- Heat Transfer Calculations for the MECO Baseline Water-Cooled Pion Production Target
- 178-v1, MECO084 -- Simulation of the Tritium Production in the Water Cooled Target
- 168-v1, MECO074 -- Comparison of the Muon Yield and Energy Deposition in the Target for Different Proton Target Design
- 988-v1, MECO071 Conceptual Design of a Water Cooled Target for MECO
- 987-v1, MECO058 MECO target thermal and structure analysis
- 084-v1, MECO010 -- Proton Target Temperature Simulation

Conceptual Design Projects

- Water-cooled pion production target & pumping station
 - Beam Power: 25 kW
 - Energy Deposition: 2150 W
 - Primary figures of merit:
 - Maximize stopped muon yield in Detector Solenoid target: $\sim 10^{11}$ stops/sec
 - Non-boiling condition on water
 - Mechanical stability of target & cooling system
- Target remote handling system: Installation, removal, storage
- Water-cooled Heat and radiation shield and pumping station
 - Protects the superconducting coils of Production and Transport Solenoids
 - Is contained inside the pion production solenoid
 - Contains the production target
 - Energy Deposition: 8 kW (Geisha)
 - Primary figures of merit:
 - Maximize stopped muon yield in Detector Solenoid – minimum bore size
 - Dimensionally stable under thermal expansion
 - Quench stability SC cable: local energy deposition
 - Dynamic heat load: total power deposition
 - Radiation load on SC cable:
 - DPA: Average number of displacements per atom
 - RRR: Resistance Reduction Ratio
 - Radiation dose in epoxy and fiber glass cable insulation

Early Prototype PS Magnet & Shield

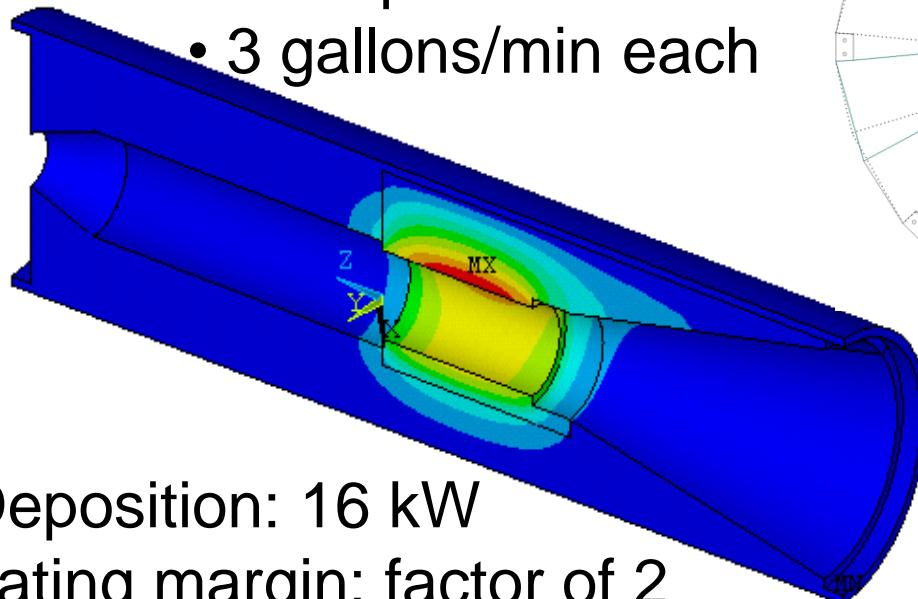
- Shield
- Length: 5m
- Diameter: 1.4 m
- Weight: 70 tons
- Composition:
 - Cu
 - W
- Heating
 - 8kW (Geisha)
 - 10.6kW (MARS)



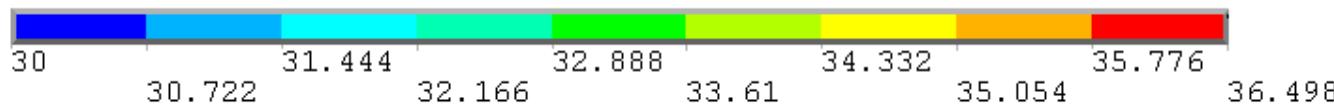
Non-Uniform Energy Deposition

1
NODAL SOLUTION

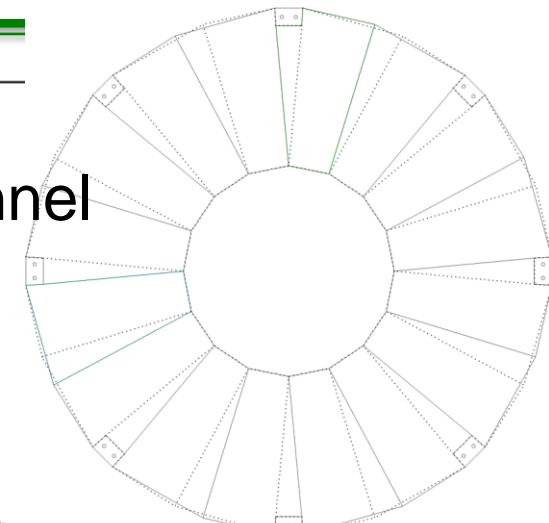
STEP=1
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
SMN =30
SMX =36.498



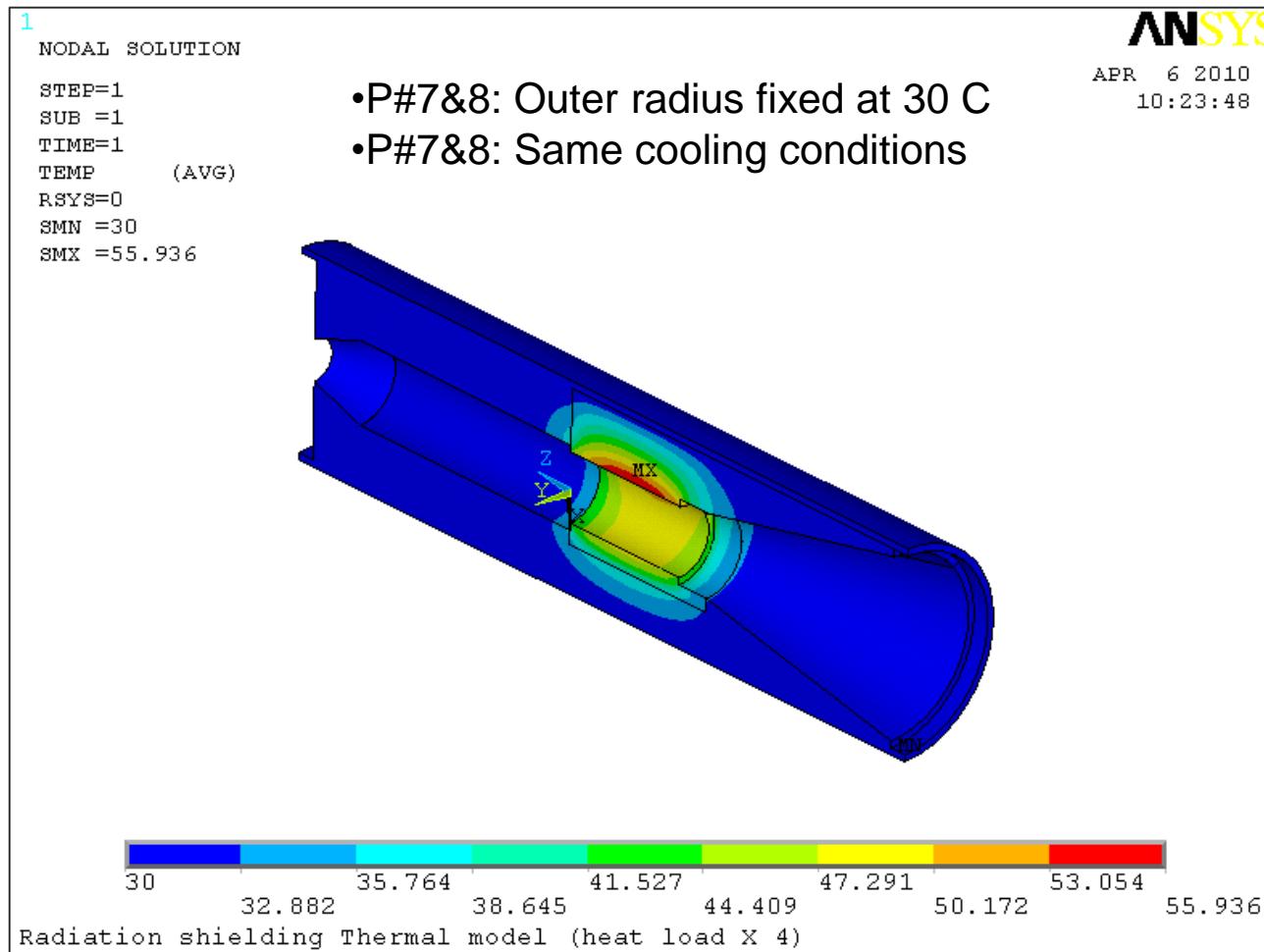
- Eight Cu cooling bars
 - U-shaped water channel
 - 3 gallons/min each
- Energy Deposition: 16 kW
 - Operating margin: factor of 2



Radiation Shielding Thermal Model



Operating Margin of 8



Current Shield Design - MARS

- PS magnet
 - Three coil design
 - Inner cryostat radius:
 - $R = 75 \text{ cm}$
- Heat and Radiation Shield
 - V. Pronskikh & N. Mokhov
 - Outer radius: 70 cm
 - Smallest cavity radius: 30 cm
 - Blue: Tungsten
 - Yellow: Copper

